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Publication date:
2009

Citation for published version (APA):
Eves, A. J., Stewart, T. P., Gay, A. P., Kemp, A. I., Easey, M., Angel, R., Thomas, N. J., & Pearce, D. A. (2009). *Developing unmanned aerial vehicles for local and flexible environmental and agricultural monitoring*. 471-476. Paper presented at New Dimensions in Earth Observation. Remote Sensing and Photogrammetry Society conference, Leicester, UK, Leicester, United Kingdom of Great Britain and Northern Ireland.
http://hdl.handle.net/2160/4573

Developing Unmanned Aerial Vehicles for Local and Flexible Environmental and Agricultural Monitoring

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Summary
Unmanned aerial vehicles (UAV) have the potential to serve as platforms for producing high resolution remotely sensed images for agricultural and environmental purposes. A programme which investigated the feasibility of UAV for agricultural and environmental monitoring is described. It resulted in the first use of a UAV in the UK to produce a NDVI (normalised difference vegetation index) map. The results are discussed in terms of the future development that will be required to make the deployment of UAVs for remote sensing a practical possibility for agricultural and environmental monitoring.

1 Introduction
Both satellite and aircraft based remote sensing are able to provide data that contains useful information for agricultural and environmental monitoring and have been available for a number of years. However, as currently available they are not able to operate with sufficient flexibility and reliability to provide timely, cost-effective, high resolution images, suitable for precision mapping for crop management or of vegetation communities. UAVs offer a potentially attractive means of providing remotely sensed data, at high spatial resolution, with flexible local control from vehicles that are very fuel efficient and operate with minimum visual intrusion. They also have the advantage that they can operate in relatively small clear weather windows and at heights where clouds are less likely to obscure their view. If clouds obstruct the view, an immediate revisit can easily be arranged (Herwitz *et al.*, 2004). Hitherto, the main use of UAVs has been military, however the cost and availability of civil versions is improving although practicality is limited by airspace restrictions (CAA, 2009). Here we report a trial of civilian use of a small UAV which took advantage of miniaturised aircraft and sensor technology to produce NDVI mapping.

2 Aims and Objectives
The aim of this work was to establish if a small UAV could be operated under UK airspace constraints to collect images of high resolution over agricultural field trials that might be suitable for agricultural monitoring. In this initial trial, acquisition of relatively simple images that could be used to map NDVI was targeted. One objective was to confirm that areas of interest could be readily located using the autopilot system on the UAV. A second objective was to see if images were of high enough quality and sufficiently free from blurring, so that they could be used to provide an adequate map of NDVI. A third objective was to check the overall practicality of the process.

3 Methodology

3.1 UAV and camera systems

The UAV system used (Fig. 1) was a bespoke UK development of the Canadian 'CropCam' system (itself a development of the MicroPilot MP-Vision[e]). The aircraft was fitted with navigation and autopilot systems followed predetermined waypoints to allow acquisition of the area required. The waypoints could be moved during flight from the ground control station. One high-resolution monochrome camera was carried under each wing in a protective pod. Each camera pointed at the nadir from fixed mounts and was fitted with one of two filters which passed a sharply defined band of radiation. One filter was tuned to the red spectral region ("R" 600 – 650 nm) and the other to the near infra red ("NIR" 770 - 860 nm). Aircraft flight parameters, navigational data, and camera video were all datalinked to the ground control station in real time. Camera video was digitised and recorded on a hard disk.

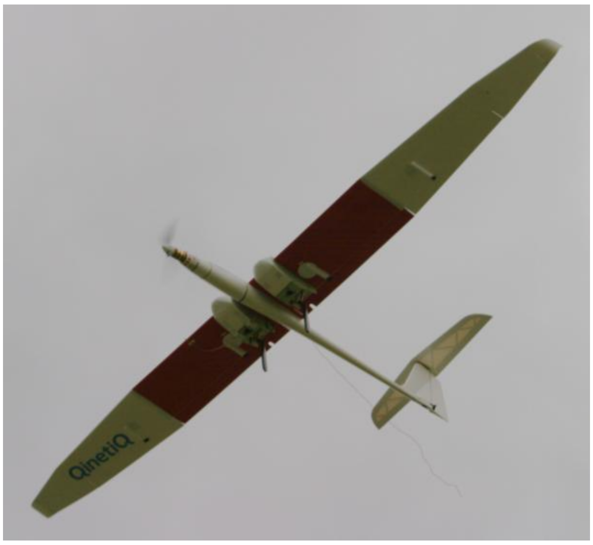

Figure 1. Underside view of the UAV showing camera pods.

3.2 Flight permissions

The UAV was operated within the CAA guidance (CAA, 2009) and approval of flights was granted by way of an exemption to conduct aerial work; as this was considered the responsible method of ensuring a safe operation. Before flights the UAV 'flight-crew' was approved for their respective roles by a representative of the QinetiQ Flying Organisation.

3.3 Flight operations

Prior to flights QinetiQ produced and developed flight operating procedures,. These were designed to mirror those used in conventional manned licensed flight operations and included maintenance procedures, aircraft documentation, check lists (pre-flight, emergencies etc) to cover the operations.

The UAV was operated with a minimum crew of two; a UAV-pilot, who operated from the UAV from a ground station (via a datalink) and a UAV-Commander who could also intervene to take manual control. Generally, flight operations were conducted with a pre-programmed flight plan (in the onboard autopilot) over the area of interest, with manual launch by the UAV-Commander. Once airborne the UAV-Commander handed over to the UAV-pilot who commanded the UAV to proceed along the pre-programmed route. Landing was always undertaken manually by the UAV Commander, in order to protect the data-gathering equipment. The third team member started and stopped video recording when the UAV was over the required area, reviewed the coverage obtained on the return leg of the flight path and suggested course amendments to the UAV pilot to ensure good coverage. Provision was made for the recording and post-flight analysis of all down-linked data

3.4 Field sites and ground truthing

The UAV was flown over two field trials: one at Bishop's Frome (BF), near Hereford, and one at Tynpynfarch, near Aberystwyth on 13-14 May 2008. At BF the trial site was a split plot design with three replicates of eight oat varieties with four nitrogen treatments (0, 70, 100, 120 kg ha^{-1} fertiliser Nitrogen added, on 30 April 2008, soil nitrogen supply 114 kg ha^{-1}) in 24 x 2m plots. At Tynpynfarch the area recorded covered both permanent grassland and late sown spring barley areas designed to give a range ground cover. Two varieties of spring barley were sown, Doyen on 19 March 2008 and Riviera on 9 April. On the day of overflights spectral reflectance (350-950 nm) of selected field plots was recorded using a dual channel spectrometer (Ocean Optics, Oxford). One channel was fitted with a cosine corrected fore-optic and was deployed 200 cm above ground and pointed at the zenith to record incoming irradiance. The other channel was fitted with a 10º field of view restrictor and was deployed at a height of 150 cm above ground level and pointed at the nadir, recording crop or reference panel (20% reflectance calibrated Spectralon, Pro-Lite Technology, Cranfield) reflected irradiance. Crop reflectance was calculated in relation to the measurements on the reflectance panel after allowing for changes in incoming solar radiation. NDVI was then calculated as:

$$NDVI= (NIR-R)/(NIR+R) \tag{1}$$

Where *R* and *NIR* are the average reflectance over the same wavebands as for the cameras.

3.5 Video data processing

Each sequence of NIR or R frames was registered separately using spatial correlation and optic flow based techniques, making bundle adjustments to correct variations in projective geometry. Once formed into a mosaic the sequences from each camera were registered, allowing for small affine corrections, to enable the NDVI to be calculated for each pixel.

Before calculation of NDVI two potential sources of error were considered, firstly differential atmospheric attenuation of NIR and R bands between the ground and cameras and secondly overall transmission differences caused by the wavelength response of the camera sensor and the transmission profile of the filter. In the first case estimates using MODTRAN (Berk *et al*., 1998) and an albedo of 0.5 with a mid-latitude summer atmospheric model suggested that over the path lengths involved the ratio of red to NIR received at the detector will vary by less than 1%, and thus could be ignored. In the second case images from both cameras (mounted in the plane) were collected from a panel of known spectral reflectivity just before the image sequences of the trial areas. This enabled a gain adjustment to be made to convert detected radiance to reflectance for each waveband before calculation of NDVI as above. Due to some remaining uncertainties in the gain calculation the final NDVI values presented were calibrated against values calculated from crops using the spectrometer in the same areas.

4 Results

In operation the UAV system proved reasonably convenient and the system and ancillary components could be carried in two small vehicles. In this experimental set-up a team of three people (UAV-pilot, UAV-Commander and Video recorder/reviewer) were able to assemble and operate the system and commence data acquisition within an hour of arriving on site. In operation, because of the restricted flight envelope and the restricted turn radius provided by the autopilot in crosswinds there was often some offset between achieved and required positions. Similarly because of roll, pitch and yaw of the UAV, the camera was not always pointing at the required area, even though it was in the correct location above the crop. These problems were solved in practice as shown in Figure 2.

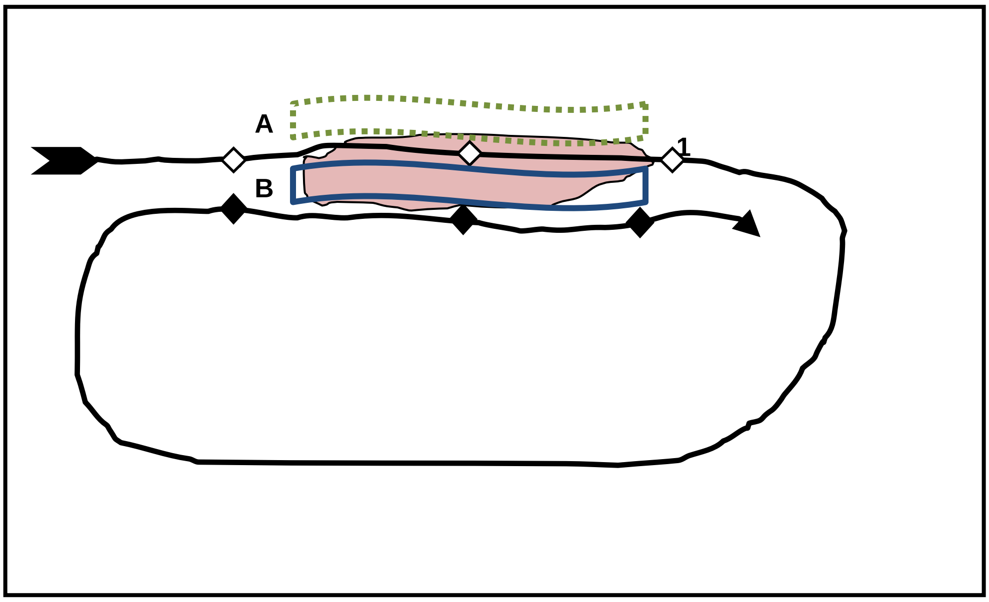

Figure 2. Modification of waypoints to ensure coverage: Pink area is to be mapped and black line is flight path. Original waypoints (◊) giving coverage **A**. *Images inspected after point 1 and modified waypoints inserted (♦) leading to improved coverage* **B**.

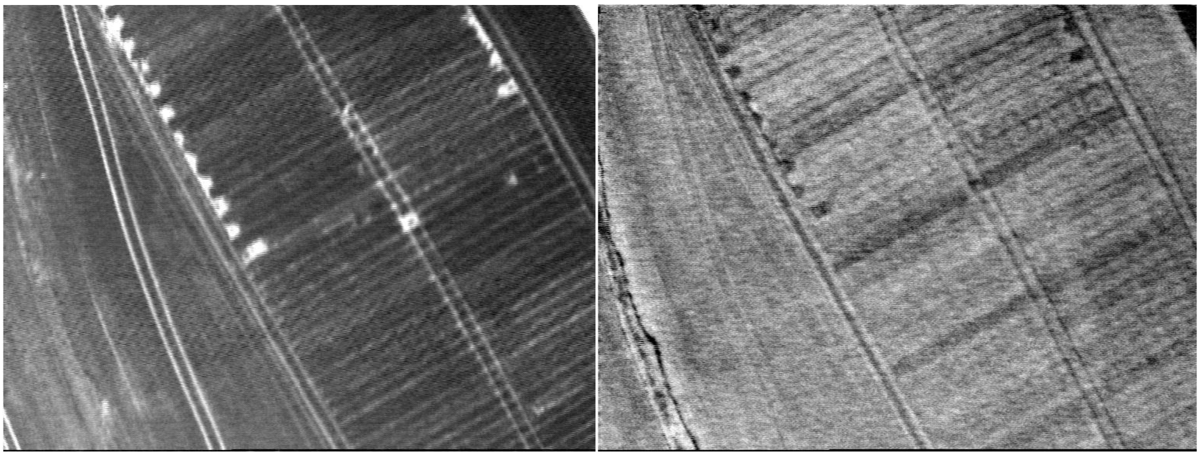

Figure 3. Frames from the R (left) and NIR (right) images of the Bishop's Frome site showing plot areas and tramlines, and areas at the ends of the plots harvested for growth analysis.

Reasonable quality images were obtained from the system as can be seen from Figure 3. However, because the records from the Bishop's Frome site were collected relatively late in the season for this winter sown crop, the crop was all at a relatively high NDVI, so few differences could be seen, and the data will not be described further. However at

Tynpynfarch in May where a very useful image was obtained which demonstrated the potential of this approach to NDVI mapping (Figure 4).

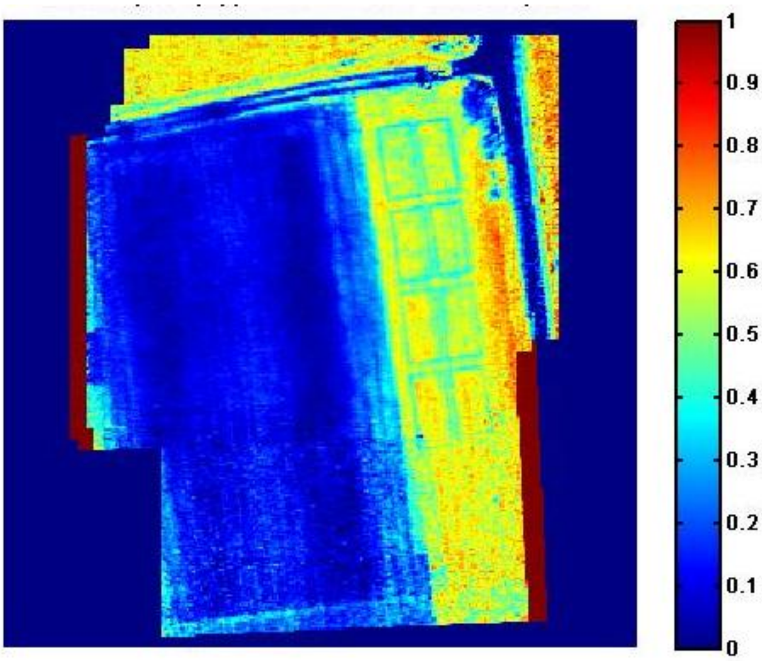

Figure 4. NDVI map of Tynpynfarch site on 13 May 2006.

5 Discussion and Conclusions

Although the possibility of UAV based mapping for agricultural purposes has been suggested previously (Herwitz *et al.*, 2004; Schellberg *et al.*, 2008) and has been demonstrated for topographic mapping (Volger *et al.*, 2009) and crop stress (Zarco-Tejada *et al*., 2009), this is the first report of UAV based NDVI mapping in the UK. It has demonstrated it is feasible to monitor crops and that images of sufficient resolution can be obtained. However, the process was not without technical problems and further development is needed before it can be regarded as routine. These include the improvement of the synchrony between the cameras, and more precise UAV position and attitude data, accurately synchronised with the image collection to simplify the process of mosaicing the images. Also methods for rapid and automated orthorectification, as has been discussed previously (Laliberte *et al.*, 2007), will need to be developed because the UAV is flying relatively close to the ground which increases the importance of this task.

As well as the technical constraints outlined above, the development of access to airspace over the sites for agricultural and environmental monitoring is required. At present, apart from the specialised airspace arrangements around Parc Aberporth in West Wales and flying below 400ft and within 500m of the operator it is difficult to get approval to fly UAV in unrestricted airspace without 90 days' notice (CAA, 2009). However, we are optimistic that further trials conducted using professional aviation procedures will develop improved access to airspace for agricultural and environmental monitoring.

At present we have only fitted simple sensors to our system and more advanced sensors, such as hyperspectral, would increase the range of vegetation types that can be distinguished, and the number of agricultural parameters estimated. Thus, our longer term aim is to use more advanced sensing on UAVs. In particular LiDAR or radar would offer information on vegetation structure (for both crops and forestry) and terrain would be advantageous, but their current volume, mass and power requirements make them more difficult to fit onto a small UAV.

6 Acknowledgements

The support of the Welsh Assembly Government, Knowledge Exploitation Fund for this work is gratefully acknowledged. The contributions of Allan Edwards (QinetiQ), Rob Appleby (QinetiQ) and David Jones (QinetiQ) to the programme were invaluable.

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